eRD25: Silicon Tracking and Vertexing Consortium

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Outline

- **Introduction to eRD25**
- Detector concepts based on 65 nm MAPS
- Status of technical developments
- EIC Silicon Consortium
- Next steps and outlook on future of the project
- Conclusion

eRD25 proposal in a nutshell

Develop a well-integrated and large-acceptance EIC vertex and tracking detector concept, based on Monolithic Active Pixel Sensor (MAPS) in a commercial 65 nm CMOS imaging technology

- The motivation for a high-resolution, low-mass charged-particle tracker remains as ever; EIC science requires it
- The work addresses the aspects of
  - 65 nm CMOS imaging technology investigation & development
  - Detector geometry optimisation, including realistic services layout
- The aims are to
  - Gain expertise on the 65 nm process
  - Arrive at a completely developed and tested detector concept
  - Identify areas needing targeted services R&D
  - Grow eRD25 into a consortium able to deliver the proposed detector to the EIC

Vertex and tracking at EIC

- All the proposed EIC detector concepts are equipped with a central Silicon Vertex and Tracking (SVT) detector
  - Vertex and tracking layers in the barrel, and disks in the forward/backward regions

- A well integrated, large acceptance vertex and tracking detector designed with high granularity and low material budget is needed to enable high precision measurements that are key to the EIC science programme

- The vertexing and tracking systems under consideration are based on two concepts investigated in our work
  - A hybrid configuration with a gas TPC at larger radii
  - A compact all-silicon configuration
  - Both simulated extensively in our previous work as eRD16 and eRD18, and continued as eRD25, leading to definition of the two Yellow Report baseline configurations

Tracking requirements from physics

Tracking requirements from PWGs						
			Momentum res.	Material budget	Minimum pT	Transverse pointing res.
η						
-3.5 to -3.0	Central Detector	Backward Detector	σp/p ~ 0.1%×p ⊕ 0.5%	~5% X0 or less	100-150 MeV/c	
-3.0 to -2.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5					100-150 MeV/c	
-1.5 to -1.0					100-150 MeV/c	
-1.0 to -0.5		Barrel	σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0						
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	σp/p ~ 0.05%×p ⊕ 1%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0					100-150 MeV/c	
2.0 to 2.5					100-150 MeV/c	
2.5 to 3.0			σp/p ~ 0.1%×p ⊕ 2%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 60 µm

From YR 11.2.2 at arXiv:2103.05419

- Spatial resolution: ~5 µm (20 µm pixel pitch)
  - ~3 µm in the vertex layers (10 µm pixel pitch)
- Material budget: <0.3% X/X0 per layer
  - < 0.1% X/X0 per vertex layer
- Integration time ~2 µs
- Low power consumption ~ 20mW/cm^2
  - Mandatory for low material budget (e.g. air cooling)

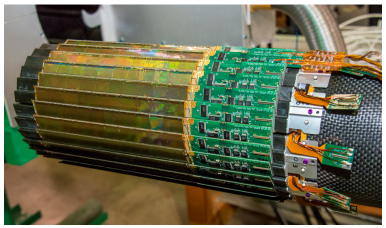
Requirements driven technology choice:
Monolithic Active Pixel Sensors (MAPS)

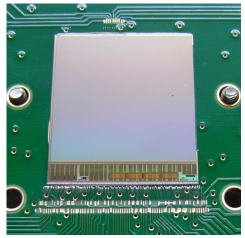
See L. Gonella, https://indico.bnl.gov/event/7449/contributions/35954/
1st EIC Yellow Report Workshop at Temple University (2020)

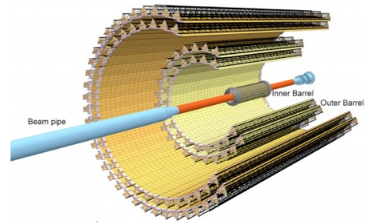
MAPS detectors

Experiment ready MAPS (i.e. production version exists)

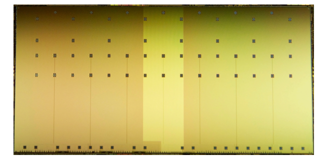
MIMOSA 28 @ STAR HFT



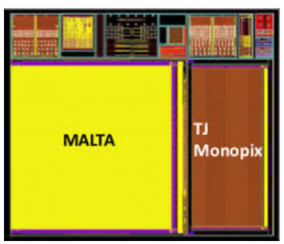




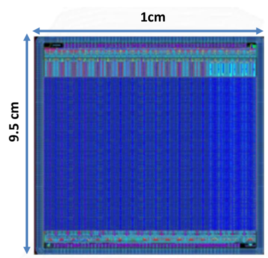
ALPIDE @ ALICE ITS



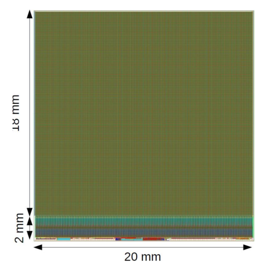
Depleted MAPS (i.e. HV/HR-CMOS) prototypes



MALTA and TJ-MONOPIX
180 nm TJ

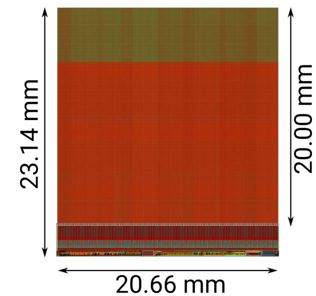


LF-MONOPIX
150 nm LFoundry



ATLASPix3
180 nm TSI

MuPix10
(soon @ Mu3e)



and more…

Conclusion:

None of the existing MAPS sensors meets all the requirements at once.
A dedicated EIC MAPS sensor is the desired solution.

See L. Gonella, https://indico.bnl.gov/event/7449/contributions/35954/
1st EIC Yellow Report Workshop at Temple University (2020)
See YR 11.2.3 at arXiv:2103.05419

New generation MAPS in 65 nm CMOS imaging technology

- A large effort is emerging to develop new generation MAPS in a commercial 65 nm CMOS imaging technology
- Large interest in the HEP community to develop this process for future experiments: CERN EP R&D programme and ALICE ITS3 project

- Improved performance in terms of granularity and power consumption that are key for precision measurements at the EIC
  - Demonstrated in simulation
- Process availability on the EIC project timescale
- Possibility to leverage on the ALICE ITS3 project
  - The ITS3 sensor specifications and development timescale are largely compatible with those of the EIC
  - Well funded, large effort at CERN, open to non-ALICE members to contribute to the R&D to develop and use the technology for other applications

Strategy:
Join the ALICE ITS3 collaboration to develop an EIC MAPS sensors in 65 nm CMOS imaging technology

See L. Greiner, https://indico.jlab.org/event/348/sessions/1224/attachments/4665/5789/open-mic.pdf
EIC Yellow Report Kick-Off meeting (2019)

ALICE ITS3 sensor

- The ALICE ITS3 project aims at developing a new generation MAPS sensor at the 65 nm node with extremely low mass for the LHC Run4 (HL-LHC)

ITS3 sensor

- Specifications meet or even exceed the EIC requirements
- Higher granularity (10 μm pixel pitch) and lower power consumption (<20mW/cm²) with respect to pre-CD0 simulation baseline (that was ITS2/ALPIDE derived)
- Also, integration time, fake hit rate and time resolution better than required at the EIC
- ITS3 fallback solution: new MAPS sensor in 180 nm CMOS imaging technology
    - Decision expected this year

ALICE

Specifications

Parameter	ALPIDE (existing)	Wafer-scale sensor (this proposal)
Technology node	180 nm	65 nm
Silicon thickness	50 μm	20-40 μm
Pixel size	27 x 29 μm	O(10 x 10 μm)
Chip dimensions	1.5 x 3.0 cm	scalable up to 28 x 10 cm
Front-end pulse duration	~ 5 μs	~ 200 ns
Time resolution	~ 1 μs	< 100 ns (option: <10ns)
Max particle fluence	100 MHz/cm^2	100 MHz/cm^2
Max particle readout rate	10 MHz/cm^2	100 MHz/cm^2
Power Consumption	40 mW/cm^2	< 20 mW/cm^2 (pixel matrix)
Detection efficiency	> 99%	> 99%
Fake hit rate	< 10^{-7} event/pixel	< 10^{-7} event/pixel
NIEL radiation tolerance	~3 x 10^{13} 1 MeV n_{eq}/cm^2	10^{14} 1 MeV n_{eq}/cm^2
TID radiation tolerance	3 MRad	10 MRad

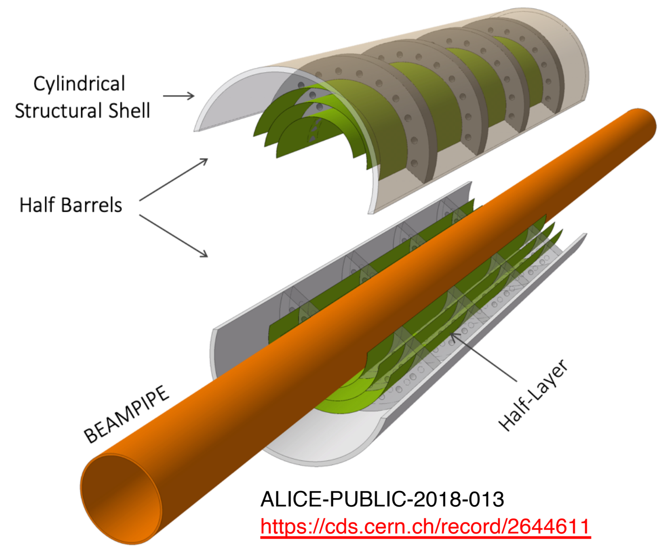
M. Mager | ITS3 kickoff | 04.12.2019 |

ALICE ITS3 detector concept

- In addition to the sensor, the ITS3 detector concept is very attractive for the vertex layers of an EIC SVT detector

ITS3 detector concept

- Three layers vertex detector, 0.12 m^2
- Truly cylindrical layers
- Design and post-processing techniques to reach an extremely low material budget of 0.05% X/X0 per layer
- Low power, wafer-scale sensor, thinned to 20-40 μm, bent around the beam pipe = air-cooling, support and services outside active area



ALICE-PUBLIC-2018-013
https://cds.cern.ch/record/2644611

Path to an EIC detector based on 65 nm MAPS

- Despite the large overlap, the EIC and ITS3 detector have some significant differences, most notably the size
  - The ITS3 is a 0.12 m^2, three layers, vertex detector
  - The proposed EIC concepts have vertex and tracking layers, disks in forward/backward direction, covering an area >10 m^2
- Projected cost and yield of stitched wafer-scale sensors not compatible with use in the EIC detector outside the vertex layers
- Tracking layers and disks will need a more conventional support structures (staves, disks) and sensor size
  - The design of a wafer-scale sensor is different from the design of a reticle-size sensor, for the same specifications → EIC sensor development needs to fork-off

The path to an EIC detector based on 65 nm MAPS thus requires to develop

1. ITS3-like vertexing layers
2. EIC variant for the staves and disks

eRD25 aims presented in July 2020

- Joining the emerging ALICE ITS3 R&D program on 65 nm technology to gain the required expertise to design a (ITS3-derived) MAPS sensor for the EIC
  - Technology evaluation program planned over two MLR submissions
- Develop and investigate the performance of well-integrated and large-acceptance tracking concepts with vertex barrel layers and forward/backward disks
  - Both hybrid and all-Si concepts to be evaluated with physics performance simulations
- Identifying areas requiring targeted services R&D
  - Plan required engineering solutions to match material budget requirements
- Start forming a consortium (beyond eRD25) able to deliver the proposed detector to the EIC

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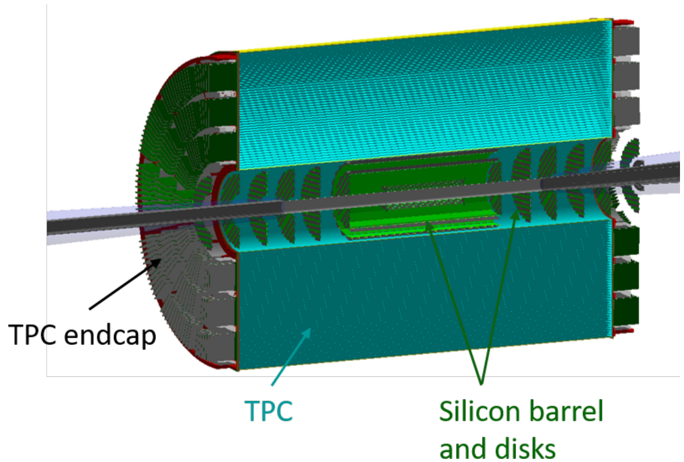
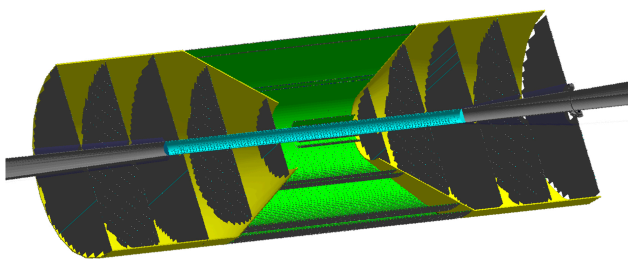
EIC Yellow Report - Tracking and Vertexing Concepts

- The recently released EIC Yellow Report presents two baseline central tracking and vertexing concepts
  - A ”hybrid” concept consisting of inner silicon barrels and disks surrounded by a time-projection-chamber
  - An “all-silicon” concept consisting of silicon barrels and discks only, with a comparatively smaller radius

- Håkan Wennlöf (Birmingham U.) and Rey Cruz-Torres (LBNL) performed most of the GEANT-based simulations for both concepts





See YR arXiv:2103.05419

EIC Yellow Report - Tracking and Vertexing Concepts

- Both concepts
  - Have characteristics that can be tracked back to the EIC model detector concept "BeAST" (c.f. A. Kiselev et al. at DIS 2016) including for example their envelope, $-1.25 < z < 1.25$ m, along the beamline
  - Use insights from prior eRD16 and eRD18 simulations and R&D, including 2 – 3 innermost vertexing barrel layers and 5 – 7 equidistant disks in the electron and hadron endcaps

- The machine design has evolved since DIS 2016: the 3.2 cm radius of the innermost beam-pipe section is an important consideration for vertexing

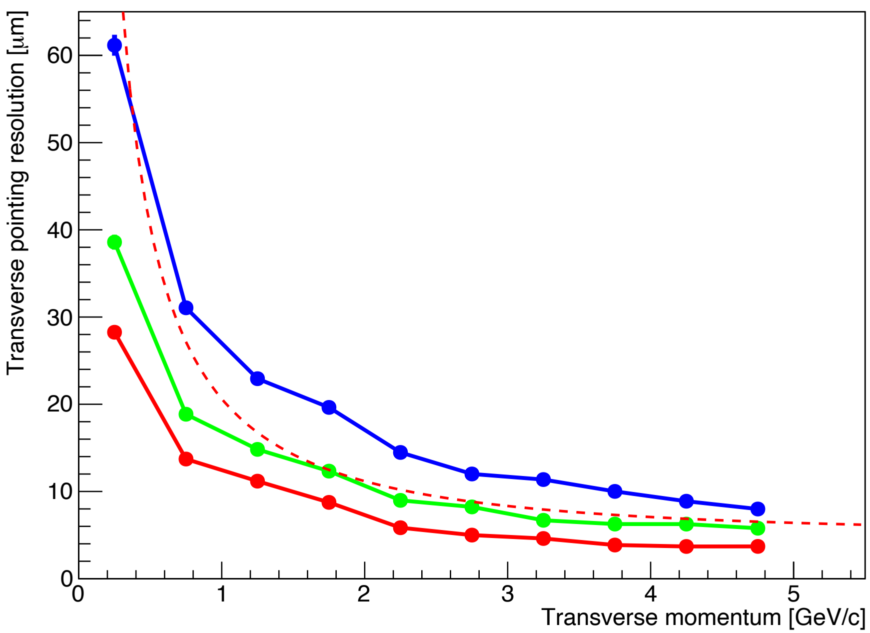
- The EIC Yellow Report has brought physics requirements/needs in much better focus
  - Both concepts tested against YR PWG requirement matrix

- As a result, the case for an ITS3-derived EIC SVT has become even stronger

Simulation driven technology choice

- Pre-CD0 simulations by eRD16 and eRD18 based on BeAST assumed
  - A beam pipe radius of 18 mm
  - An ITS2-derived detector concept with 0.3/0.8% X/X0 in vertex/tracking layers and a 20 um pixel pitch
  - Note that a pixel pitch of 20 um is NOT the ALPIDE, ALPIDE has ~28um pitch.

- With the post-CD0 beam pipe radius of 31 mm, initial simulations highlighted the need for ITS3 like spatial resolution and material budget to reach required vertex resolution



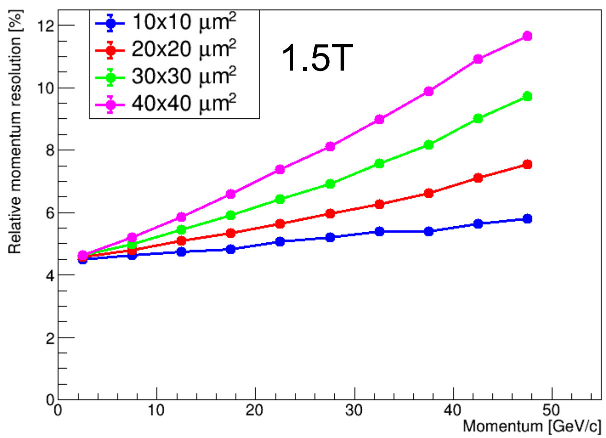
	Green	Blue	Red (ITS3-derived EIC SVT)
Beam pipe radius [mm]	18	**31**	**31**
x/X0 vertex	0.3%	0.3%	**0.05%**
x/X0 tracking layers	0.8%	0.8%	0.8%
Pixel pitch [um]	20	20	**10**

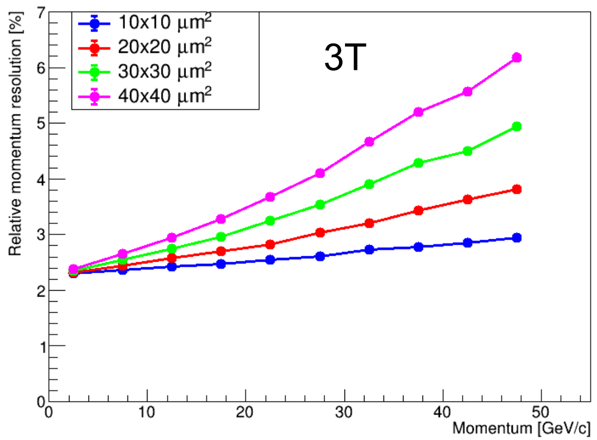
Pions, momentum range up to 5 GeV/c
$-0.5 < \eta < 0.5$
Uniform 1.5T magnetic field

--- YR PWG requirement

Simulation driven technology choice

- Initial simulations have also shown the that the relative momentum resolution in the forward region (eta = 3) is also strongly affected by spatial resolution

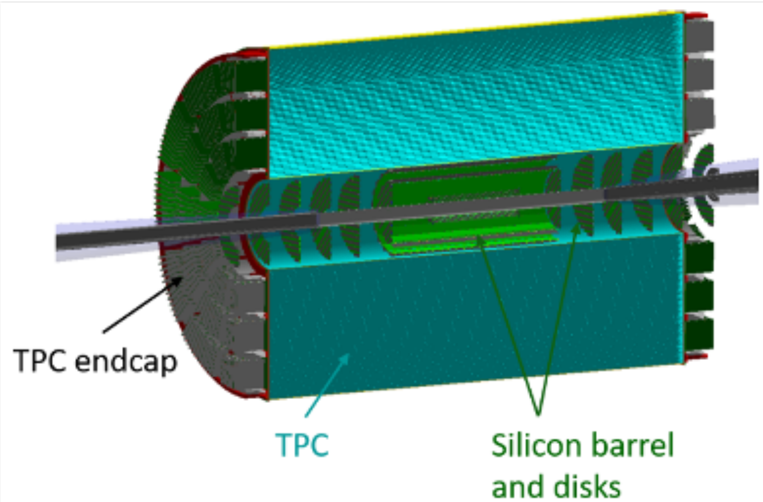




Forward region; η = 3
Single electrons fired from centre
Magnetic field: uniform 1.5 T and 3 T
Vertex layers and disks: 0.3% x/X0
Tracking layers: 0.8% x/X0
All disks hit

See H. Wennlöf at https://indico.jlab.org/event/400/contributions/6529/ and http://cern.ch/go/xKk6

EIC YR – Hybrid Tracking and Vertexing Concept



10μm pixel pitch

x/X_0 = 0.05% per vertexing layer (1 – 3)
x/X_0 = 0.55% per tracking layer (4 and 5)
x/X_0 = 0.24% per disk (1 – 7)

The material budget figures come from the estimates presented in July (extrapolation from ITS2 using ITS3 sensor specifications)

Layer	Length	Radial position
Layer 1	420 mm	36.4 mm
Layer 2	420 mm	44.5 mm
Layer 3	420 mm	52.6 mm
Layer 4	840 mm	133.8 mm
Layer 5	840 mm	180.0 mm
TPC start	2110 mm	200.0 mm
TPC end	2110 mm	780.0 mm

(a) Barrel region

Disk	z position	Inner radius	Outer radius
Disk 1	220 mm	36.4 mm	71.3 mm
Disk 2	430 mm	36.4 mm	139.4 mm
Disk 3	586 mm	36.4 mm	190.0 mm
Disk 4	742 mm	49.9 mm	190.0 mm
Disk 5	898 mm	66.7 mm	190.0 mm
Disk 6	1054 mm	83.5 mm	190.0 mm
Disk 7	1210 mm	99.3 mm	190.0 mm

(b) Disk region

See Håkan Wennlöf et al., https://indico.bnl.gov/category/276 and Yellow Report Ch 11.

EIC YR – Hybrid Tracking and Vertexing Concept

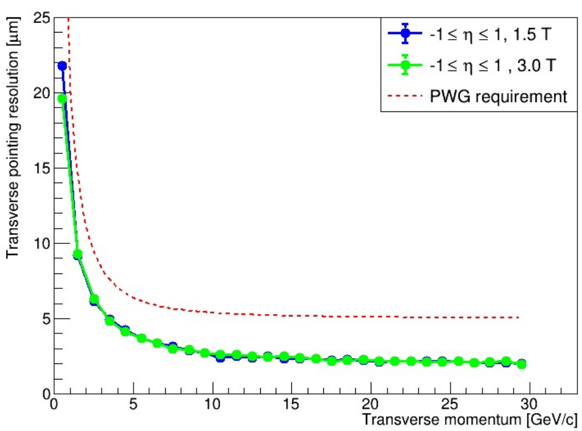
- Reminder: requirements we are testing against

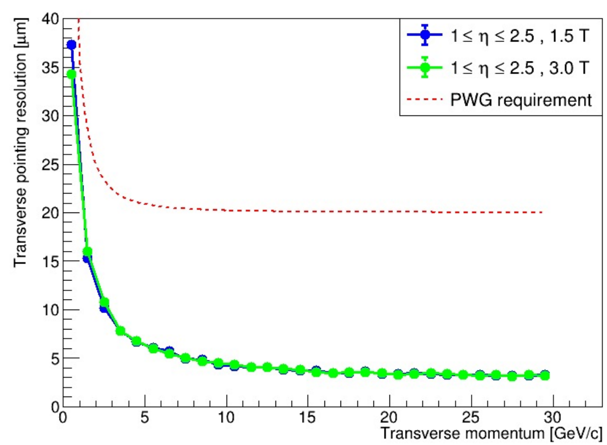
Tracking requirements from PWGs

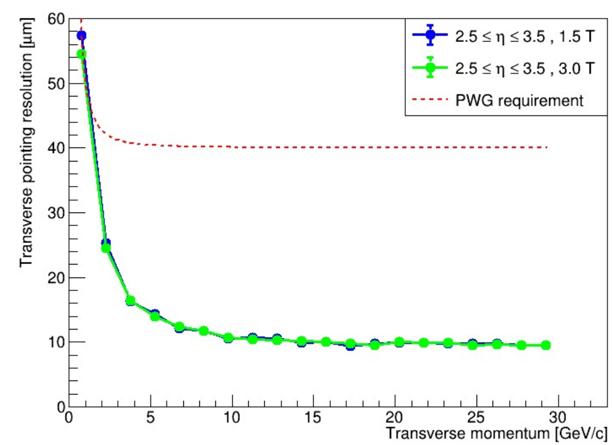
η			Momentum res.	Material budget	Minimum pT	Transverse pointing res.
-3.5 to -3.0	Central Detector	Backward Detector	σp/p ~ 0.1%×p ⊕ 0.5%	~5% X0 or less	100-150 MeV/c	
-3.0 to -2.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5					100-150 MeV/c	
-1.5 to -1.0					100-150 MeV/c	
-1.0 to -0.5		Barrel	σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0						
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	σp/p ~ 0.05%×p ⊕ 1%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0					100-150 MeV/c	
2.0 to 2.5					100-150 MeV/c	
2.5 to 3.0			σp/p ~ 0.1%×p ⊕ 2%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 60 µm

From YR 11.2.2 at arXiv:2103.05419

- Transverse pointing resolution
  - Satisfies the YR PWG requirements both at 1.5 T and 3 T field





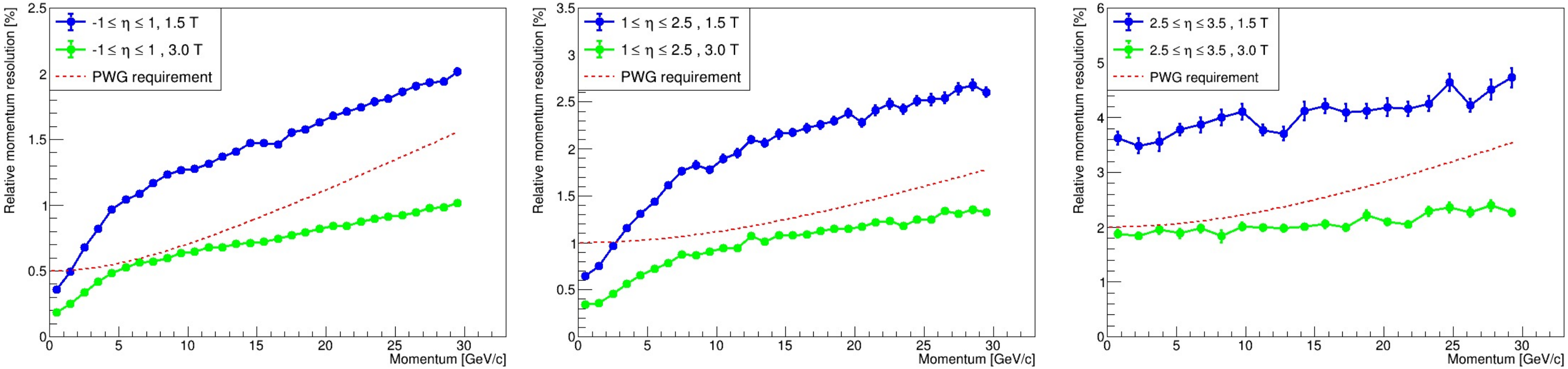


1.5T, 3.0T, PWG requirement

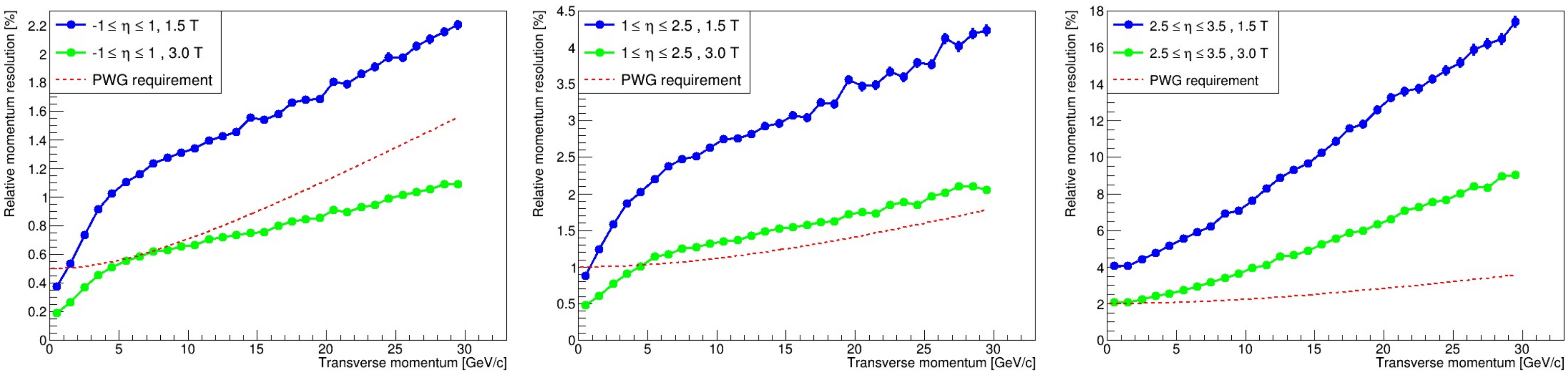
EIC YR – Hybrid Tracking and Vertexing Concept

- Relative momentum resolution

1.5T, 3.0T, PWG requirement

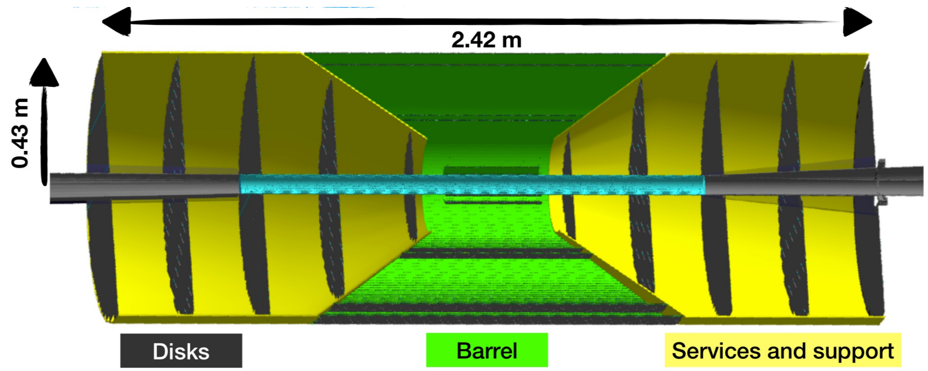


- Transverse relative momentum resolution



- Physics requirements present a challenge in the forward regions, despite the low traversed mass and 10μm pixel pitch

EIC YR – All-Silicon Tracking and Vertexing Concept



Barrel layer	radius [cm]	length along z [cm]
1	3.30	30
2	5.70	30
3	21.00	54
4	22.68	60
5	39.30	105
6	43.23	114

10 μm pixel pitch, x/X0 = 0.3% per layer, disk

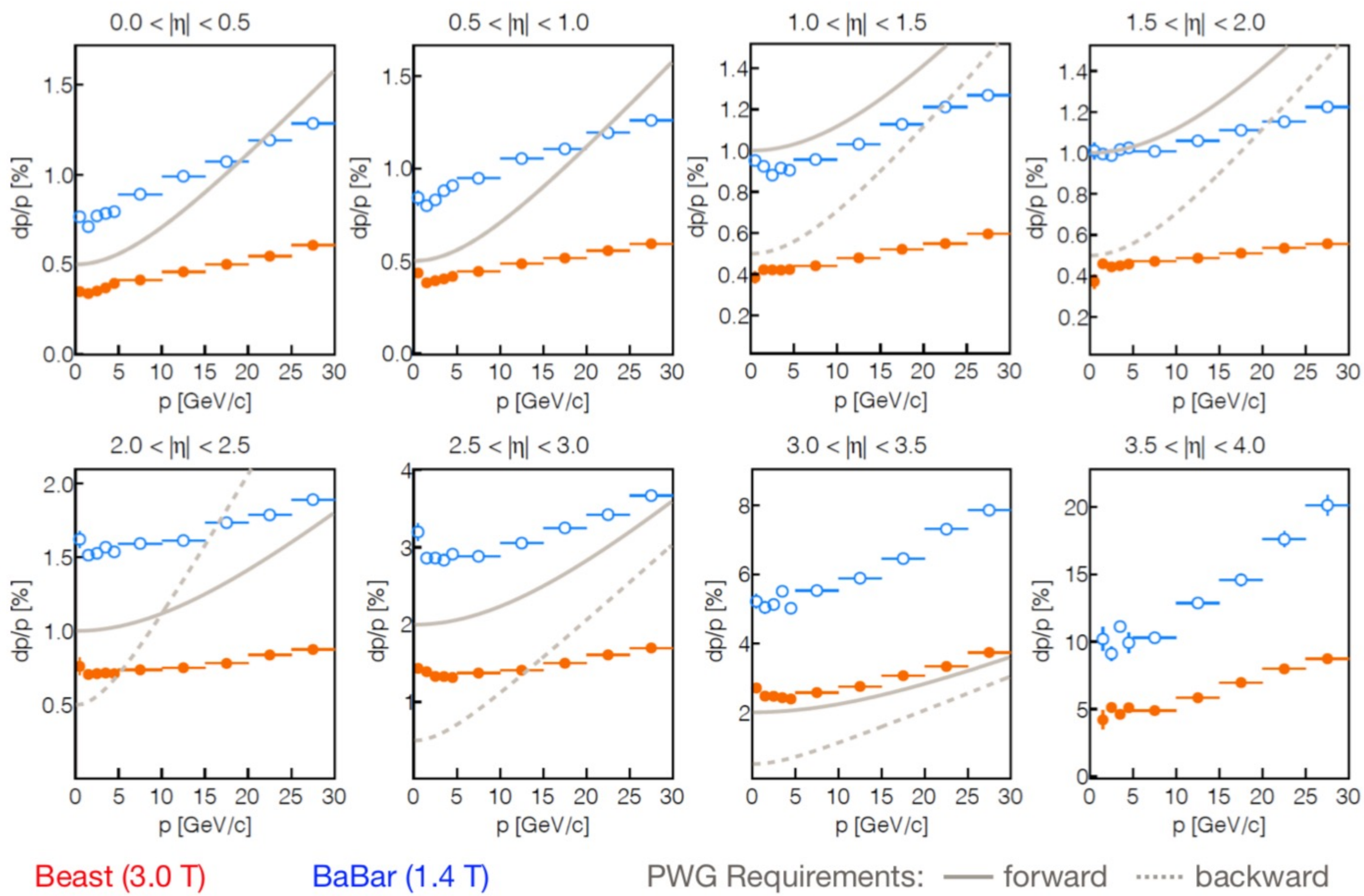
Disk number	z position [cm]	outer radius [cm]	inner radius [cm]
-5	-121	43.23	4.41
-4	-97	43.23	3.70
-3	-73	43.23	3.18
-2	-49	36.26	3.18
-1	-25	18.50	3.18
1	25	18.50	3.18
2	49	36.26	3.18
3	73	43.23	3.50
4	97	43.23	4.70
5	121	43.23	5.91

- Note
  - The hybrid concept has 3 vertexing layers, whereas the all-silicon concept has 2; vertexing resolution is near-identical, however, differences exist in threshold and redundancy
  - The all-silicon concept has 2 x 5 disks, whereas the hybrid has 2 x 7, again spanning the range from prior eRD16 and eRD18 work
  - The outer radius was originally chosen such that dp/p for 20 μm pixel pitch is similar to dp/p of the hybrid concept for $-1 < \eta < \sim 1$

Rey Cruz-Torres et al., https://indico.bnl.gov/category/276 and Yellow Report Ch 11.

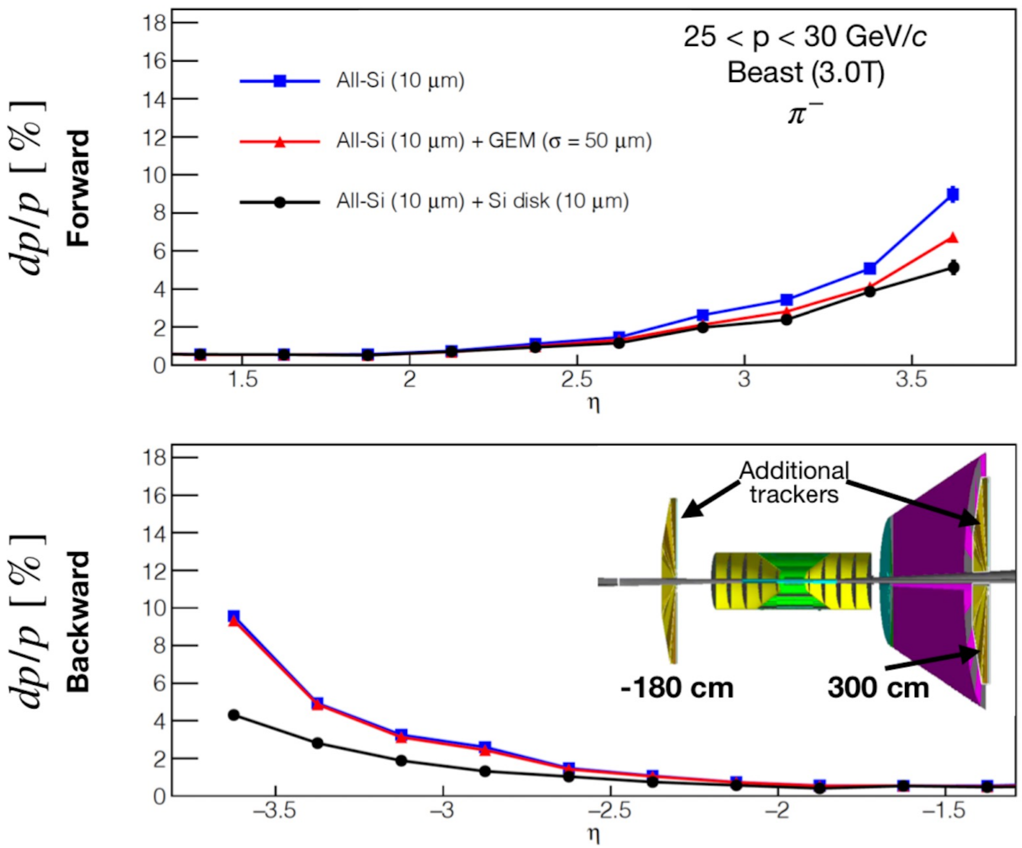
EIC YR – All-Silicon Tracking and Vertexing Concept

- Physics requirements present a challenge in the forward regions, despite the low traversed mass and 10μm pixel pitch



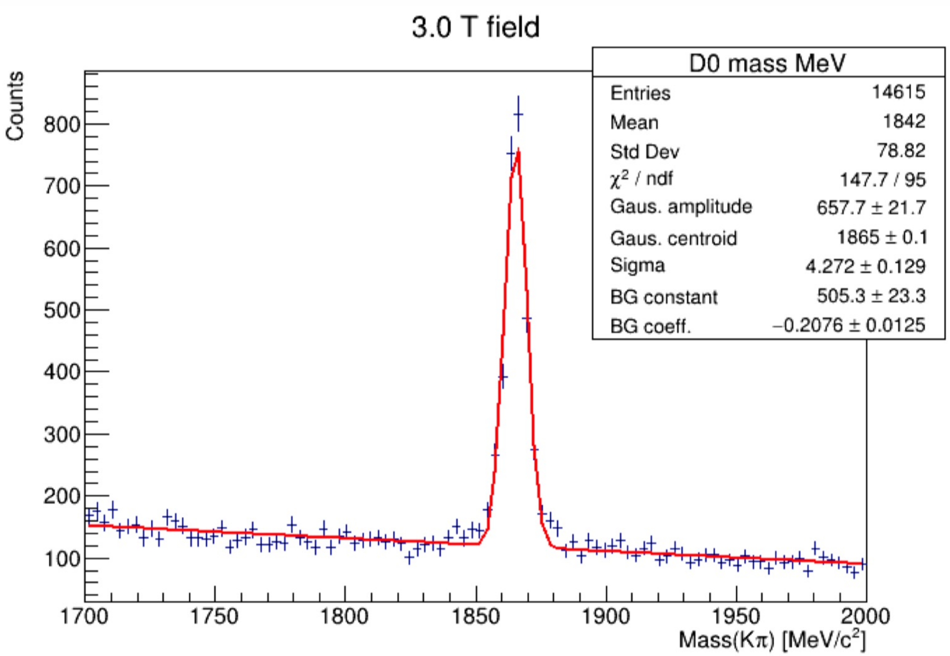
EIC YR – All-Silicon Tracking and Vertexing Concept

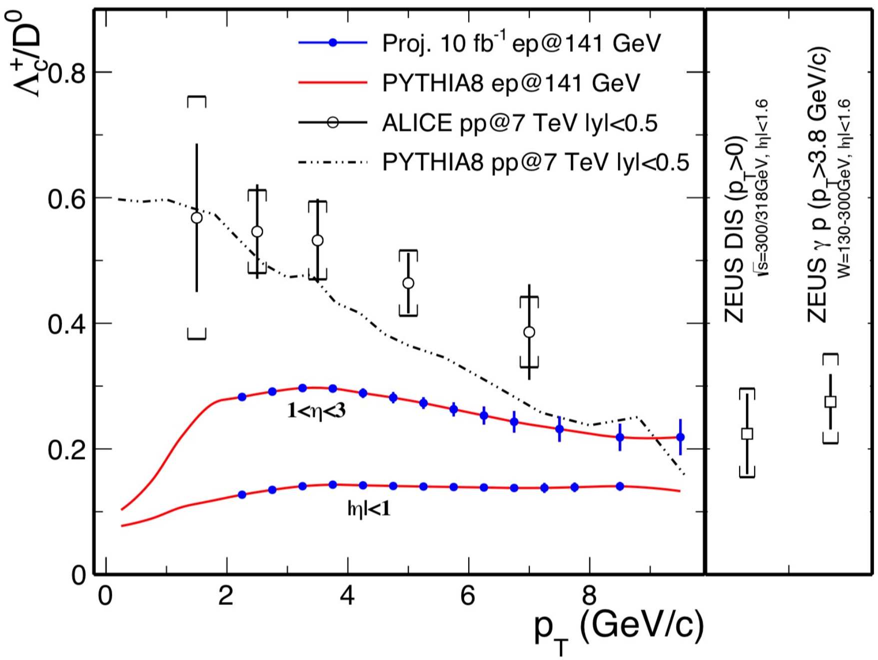
- Initial studies were made to address this challenge
- Momentum resolutions can be enhanced by complementing detectors with additional tracking stations
- An additional large-*z* detection layer would benefit PID with a forward RICH



See also arXiv:2102.08337 (Figs 6 and 7)

EIC YR - Physics studies with both tracking concepts





- GEANT-based and “fast” simulations were both used to study a range of physics topics, including e.g. F2-charm, the baryon to meson ratio, and others
  - EIC Yellow Report
  - John Arrington et al, arXiv:2102.08337
  - Håkan Wennlöf, Ph.D. thesis (in preparation)

EIC YR - Tracking and Vertexing Concepts, summary

- These and many other studies were reported during EIC YR workshops and meetings
  - 1st – 4th EIC Yellow Report Workshop - https://indico.bnl.gov/category/220/
  - Tracking Working Group - https://indico.bnl.gov/category/276/
  - Jets and Heavy Quarks Working Group - https://indico.bnl.gov/category/290/
  - See also backup slides for minimum p_T studies, angular distributions, effect of beam crossing angles

- We built on insights from our prior work as eRD16 and eRD18 to arrive at the – “hybrid” and “all-silicon” - tracking and vertexing solutions for the EIC general purpose detector concept(s)
- Based on the physics needs specified by the EIC User Community in the recently completed Yellow Report, we believe that the case for the development of a dedicated EIC MAPS leveraging the ongoing ITS3 has only become stronger
- Among other factors, the 10 μm pixel pitch demonstrably serves displaced vertex resolution and precise momentum measurement of charged particles in the electron and hadron endcap regions within the overall constraints of the current general purpose detector concepts

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- **Status of technical developments**
- EIC Silicon Consortium
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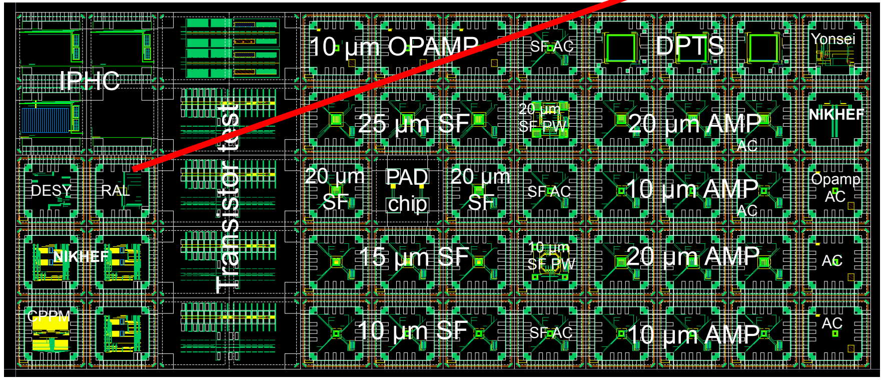
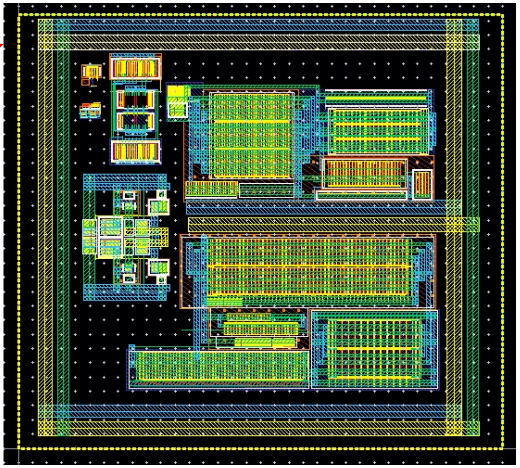
Sensor development: MLR1

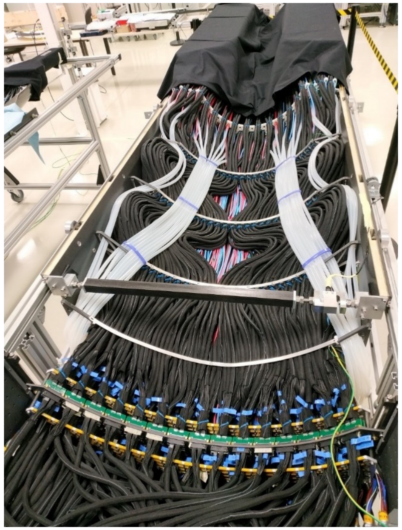
- We have actively engaged with the sensor design activities of the ITS3 Work Package 2 (WP2)
- The first submission in the TowerJazz 65 nm CMOS imaging process (ISC) took place in December
  - MLR1 (Multi-Layer Reticle) submission
  - Technology exploration and prototype IP blocks for future sensors
- The MLR1 comprises
  - Transistor Test Structures (CERN)
  - Analogue and digital Pixel Test Structures (IPHC, DESY, CERN)
  - Bandgap/VCO (NIKHEF)
  - High Speed Structures (RAL)
  - Ring Oscillator (CPPM)





Services: Investigation of powering options

- EIC detectors will have a large acceptance for tracking, PID and calorimetry where material budget is a concern
- The largest contributor to mass in the services of the tracking detector are the power and return cables



Example of services for outer layers half-barrel of ALICE ITS using conventional LDO regulated architecture

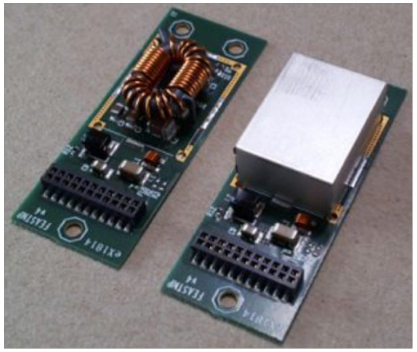
Other powering architectures (DC-DC converters, serial powering) have potential to significantly reduce the dead material in the detector volume

- We have completed an initial exploration quantifying the service loads that could be expected for an ITS-3 like sensor using DC-DC converter or serial powering schemes in reasonable architectures
  - https://www.eicug.org/web/sites/default/files/Powering-options-for-an-EIC-silicon-tracker.pdf

Services: Investigation of powering options

- Using the existing ITS2 upgrade detector as a reference we explored
  - Scaling material budget for ITS-3 like sensors
  - Multiple powering connection topologies
  - Calculating wire and FPC (Al conductor) thicknesses depending on architecture and topology
  - Including estimates of all the material involved in each scenario

FEAST MP radiation and magnetic field tolerant DC-DC converter (CERN)

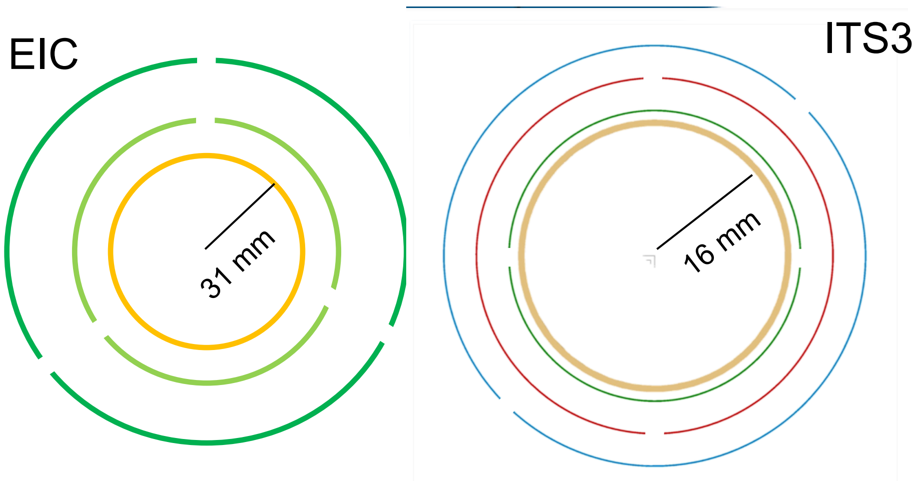


	Material budget (as a percentage of reference: ALICE ITS-2)			Development time (prototyping and characterization)
	Analog/digital/ground cable mass (outside detector volume)	PCB surface (detector sides)	FPC power bus material budget (inside detector volume)	
ALICE ITS-2 architecture (ITS-3 sensor modules) *	~50%	~100%	~66%	~1.5 years
DC-DC converters	3.125% - 6.25%	87% - 208%	~40%	~1.5 years
Serial powering	8% - 32%	5% - 20%	30 - 40%	~5 years

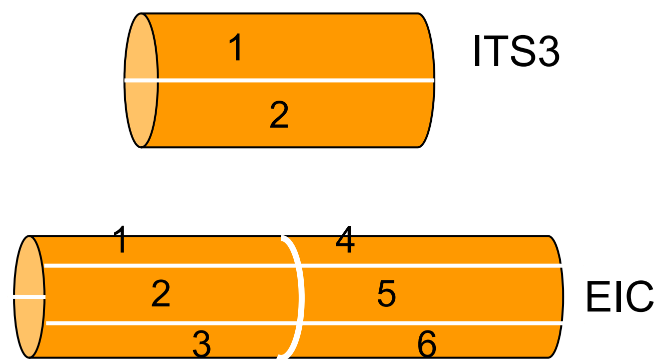
EIC SVT strawman design – Vertex layers

- Use ITS3 detector sensor and detector layout, adapted to larger radii and length of the EIC vertex layers
    - Three bent sensors needed to cover the larger radii
    - Along the length, two sensors may be needed to cover the length depending on detector configuration/further optimisations
    - In total, three to six sensors per layer (instead of two in ITS3)
- Deploy wafer-scale sensor as in ITS3 (with different length if needed)
- Material budget X/X0 ~0.05% per layer as in ITS3
- Services may come out on both sides of EIC vertex layers

Cross-sectional view – not to scale

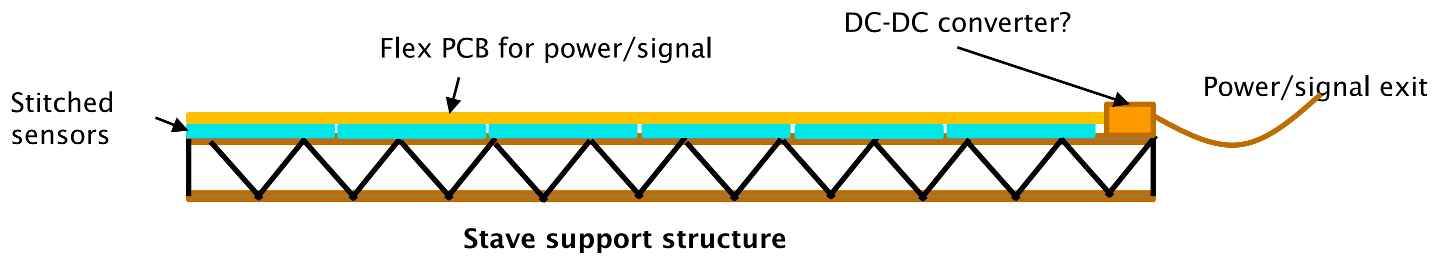


Side view – not to scale, only one layer



EIC SVT strawman design – Tracking layers and disks

- Staves and discs will be based on a forked EIC specific sensor design based on the ITS3 sensor
  - Same functionality and interfaces as ITS3 sensor, stitched but not wafer-scale
  - Stitched sensor layout/size will need to be optimized to provide the coverage needed for each stave and disk
  - Optimization will consider yield estimates from first engineering run
- Staves derived from ITS2 structures; discs composed of overlapping staves or low mass CFC support discs
- Material budget estimate
  - Tracking layer X/X0 ~0.55%
  - Disks X/X0 ~0.24 %



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EIC Silicon Consortium

- eRD25 has grown into the the EIC Silicon Consortium

- EIC SC current members
  - LBNL, BNL instrumentation division, UK collaboration (currently University of Birmingham, RAL, Brunel University - London), JLAB, ORNL, CCNU – Wuhan, INFN groups (currently Bari, Trieste), Institute of Modern Physics (IMP, China)
  - Other groups expressing interest in participating but EIC SC membership has not been formalized yet

- Mission statement from the response to the Call for Expressions of Interest for Potential Cooperation on the EIC Experimental Program - November 2, 2020: https://indico.bnl.gov/event/8552/contributions/43219/
  - *"The goal of this consortium is to develop a MAPS sensor and associated powering, support structures, control and ancillary parts as necessary to produce a detector solution for silicon tracking for the central tracking parts of an EIC detector. … The members of this consortium believe that the most successful path to achieve this goal is to join the ongoing effort at CERN to develop a new MAPS sensor based on the Tower-Jazz 65 nm process for use in the upcoming ALICE ITS3 upgrade."*

EIC Silicon Consortium

- The EIC SC is open to institutes from different emerging collaborations interested to work on the proposed sensor solution for their specific EIC detector implementation
  - Similar concept to the CERN RD groups (such as RD50, RD53)
  - This will maximise the successful delivery of the technology with the lowest cost to the project

- The EIC SC status
  - Currently defining work packages with associated tasks assigned to groups based on interest and capabilities
  - Work packages and activities largely aligned with ITS3 structure
  - Continued discussions with ITS3 management for EIC SC institutes to join the relevant ITS3 WP
  - Regular meetings to start in a few weeks

- To promote our concept and stimulate interest in EIC SVT development, we co-organized (with JLab) the “SVT EIC - a Silicon Pixel-Based Particle Vertex and Tracking Detector Towards the US EIC” workshop - https://www.jlab.org/conference/SVT-EIC

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Short term plan (i.e. FY21)

- MLR1 testing
  - MLR1 expected from foundry in May
  - Planned functional testing of our IP block, as well as performance testing of analogue and digital structures
  - Birmingham MC40 cyclotron and LBNL 88” cyclotron available for NIEL, TID and SEE studies
  - Discussions started to join ITS3-WP3 on sensor testing

- MLR2 submission
  - ITS3-WP2 started planning the MLR2, including a first stitched pixel matrix, submission in Q3-21
  - RAL providing guidance on stitching given their previous experiences
  - BNL and Brunel to join as soon NDA is circulated by CERN
  - Discussions with ITS3 designers team is being organised to define our participation to the MLR2 – our goal is to get as much expertise as possible with the stitched sensor design that will be the base for further sensor development

Short term plan (i.e. FY21)

- Power options prototyping
  - Refine estimates of required mass
  - Begin prototyping some of the more promising architectures to measure the operational characteristics
    - This will proceed apace the sensor development
  - Start investigating low mass cooling schemes

- Simulation efforts will continue in the context of the ongoing detector collaboration forming exercises and the corresponding specific detector designs
  - Integration of EIC SVT into the overall detector concepts, including services and supports

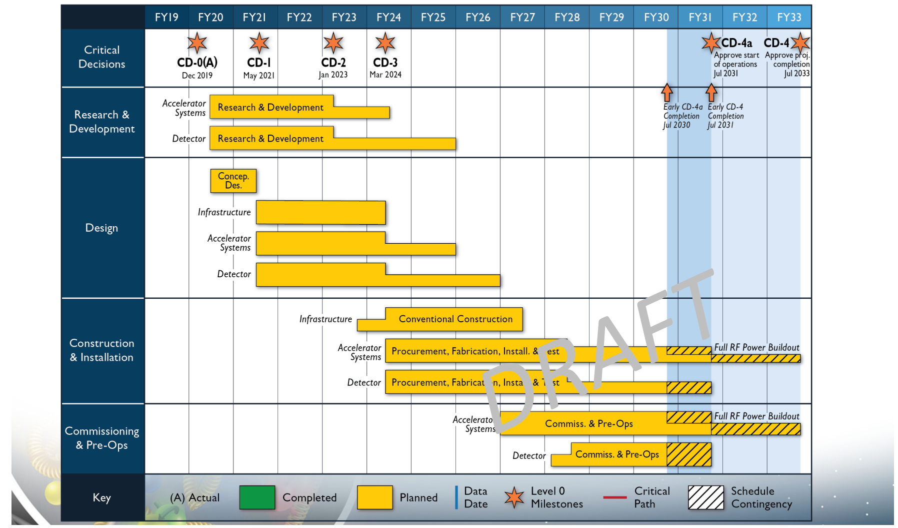
- Fully transition eRD25 to the EIC SC
  - Complete WP structure and task assignment
  - Facilitate EIC SC work within ITS3

Timeline

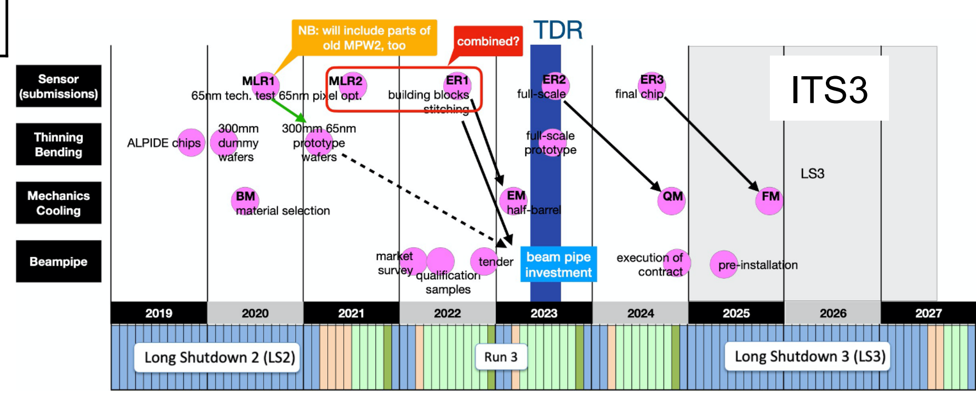
- The timeline for the development is tied to the sensor development

Year	Main tasks
2021	Submission of the second MLR.
2022	Submission of the first engineering run (ITS).
2023	Submission of the first engineering run (EIC variant), second engineering run (ITS3).
2024	Submission of the second engineering run (EIC variant).
2025	Integration of prototype sensors into disc and stave. Possible contingency submission of EIC variant.

Proposed Schedule – New!



See J. Yeck,
https://indico.bnl.gov/event/10825/contributions/46080/
Kick-off meeting for an EIC detector at IP6, March 2021



Timeline - detailed

- The timeline for the development is tied to the sensor development

Year	Detailed tasks
2021	• Testing and characterization of MLR1 • Sensor design for MLR2 • MLR2 submission • R&D into powering, stave/disc construction, cooling, overall infrastructure
2022	• Testing and characterization of MLR2 • Sensor design for ITS3 ER1 • ITS3 ER1 submission • R&D + prototyping into powering, stave/disc construction, cooling, overall infrastructure
2023	• Testing and characterization of ITS3 ER1 and assessment of yield • Assessment and planning for EIC sensor fork of ITS3 design • Fork off sensor design and work on EIC variant for staves and discs (may move to next year depending on results) • ER submission for EIC variant sensor (EIC ER1) for staves and discs • Detailed prototyping into powering, stave/disc construction, cooling, overall infrastructure • Investigation of adaptation of ITS3 design for use in EIC vertex layers (different radii, # layers, services from both ends to meet length requirements, etc.) with ITS ER1
2024	• Testing and characterization of EIC ER1 and assessment of yield • Si design for EIC ER2 • EIC ER2 submission for EIC variant sensor for staves and discs • Detailed prototyping into powering, stave/disc construction, cooling, overall infrastructure using EIC ER1 prototypes • Adaptation of ITS3 design for use in EIC inner layers with ITS2 ER2 (or integration of design into EIC ER2 if necessary).
2025	• Testing and characterization of EIC ER2 and assessment of yield • Complete stave and disks prototypes with EIC ER2 • Vertex layers prototypes with ITS2 ER3

Projected R&D costs to reach production (CD-3) level

CY	Sensor (M$)	Infrastructure (M$)	Total (M$)
2022	0.74	0.38	1.12
2023	0.85	0.77	1.62
2024	1.2	0.75	1.95
2025	0.64	0.64	1.28

- Sensor category includes silicon designers, cost of silicon submissions, testing systems, etc. We assume that 25% of the silicon designer time (largest expense) comes from EIC R&D funding. 75% is funded by other sources or contributed
- Infrastructure category includes stave and disc design and prototype, cooling, power, RDO, mechanics and integration and services reduction
- All costs using LBNL labor rates
- Full itemized spreadsheet available upon request

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Conclusion

- The eRD25 project is well on track to deliver the proposed planned of work for FY21

eRD25 aims presented in July 2020

- Joining the emerging ALICE ITS3 R&D program on 65 nm technology to gain the required expertise to design a (ITS3-derived) MAPS sensor for the EIC
  - Technology evaluation program planned over two MLR submissions
- Develop and investigate the performance of well-integrated and large-acceptance tracking concepts with vertex barrel layers and forward/backward disks
  - Both hybrid and all-Si concepts to be evaluated with physics performance simulations
- Identifying areas requiring targeted services R&D
  - Plan required engineering solutions to match material budget requirements
- Start forming a consortium (beyond eRD25) able to deliver the proposed detector to the EIC

L. Gonella | eRD25 FY21 report | EIC Detector R&D meeting, 24 March 2021 10

- We are now transitioning into the EIC SC with detailed R&D plan and schedule, and projected cost estimates to develop an ITS3-derived EIC SVT ready for production

Backup

eRD25 origins

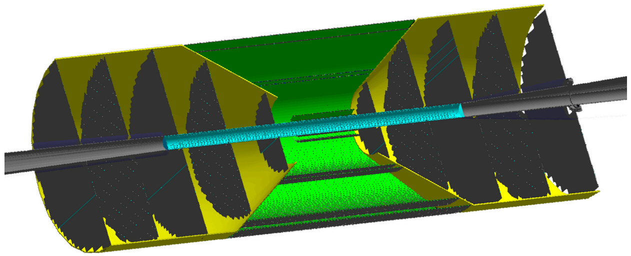
- eRD25 grew out of eRD16 and eRD18 over the past 6 months
- The former eRD16 initially focused mostly on forward/backward charged particle tracking with disks using MAPS
- The former eRD18 initially focused on central vertexing with MAPS barrels, and sensor development (Depleted MAPS)
- eRD16 and eRD18 increasingly worked together over the years; barrel and disks are closely related, mutual technical interests
  - For example, Håkan Wennlöf (eRD18) was first to study the optimal positioning of the innermost disk w.r.t. the innermost barrel vertex layers
  - Leo Greiner (eRD16) initiated the group's effort with ITS3 sensor R&D
- Both groups studied integrated tracking and vertexing concepts, hybrid as well as the first all-silicon concepts for EIC

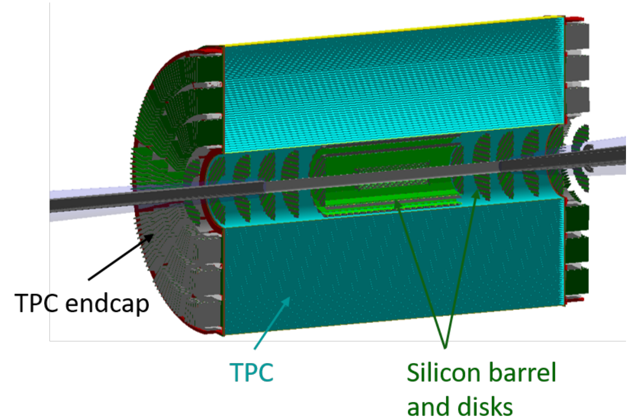
eRD25 origins

- In the January 2020 EIC generic detector R&D meeting, eRD16 and eRD18 proposed to form a consortium to work toward an ITS3 based EIC silicon vertex and tracking detector
- The committee encouraged the plan to merge into a unified silicon tracking R&D effort, open to new collaborators and take advantage of emerging technological opportunities
- We have done so by forming the “eRD25: Silicon Tracking and Vertexing Consortium” (this proposal), and starting the “EIC Silicon Consortium” (discussed later in this presentation)
- The eRD25 proposal builds on the prior work of eRD16 and eRD18, and presents a design path to an EIC silicon vertex and tracking detector, starting with the development of the sensor technology

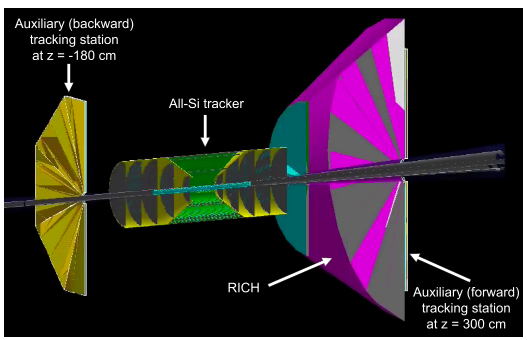
YR concepts based on MAPS SVT detector

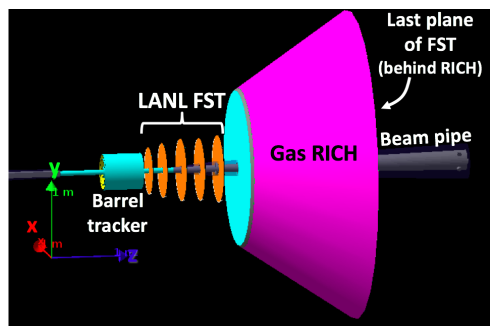
- YR baseline concepts
  - All-silicon and hybrid (MAPS + TPC)

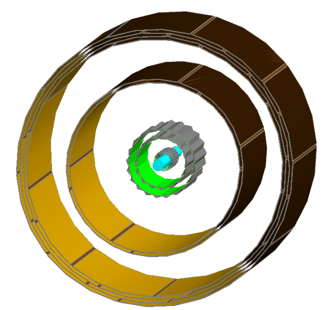




- Alternative tracking options exist in the backward and forward tracking regions, also MPGD based barrel



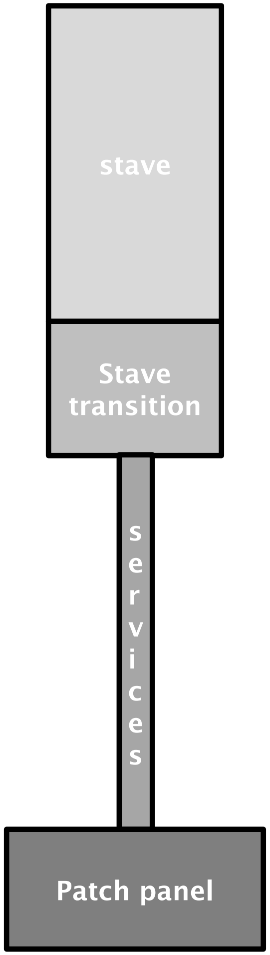




For more details see YR 11.2 at arXiv:2103.05419

The MAPS technology to satisfy the requirements of the central detector can be the same for different EIC detector configurations

ITS3-derived EIC SVT – Material budget estimates



	Stave X/X0	Stave transition (per 100 cm^2 of Si surface)	Services (per 100 cm^2 of Si surface)	Patch panel (per 100 cm^2 of Si surface)
ITS3 like vertexing	~0.1%	6.66 cm^3 of material with X/X0 of 0.0684 per traversed cm	2.96 cm^2 cross section with X/X0 of 0.022 per traversed cm	4.32 cm x 1cm x 1 cm with 0.102 X/X0 per traversed cm
ITS3 like barrel (up to 1.5m length)	0.55 %	4.286 cm^3 of material with X/X0 of 0.0684 per traversed cm	1.905 cm^2 cross section with X/X0 of 0.022 per traversed cm	2.778cm x 1cm x 1 cm with 0.102 X/X0 per traversed cm
ITS3 like disc (up to 60 cm diameter)	0.24%	6.66 cm^3 of material with X/X0 of 0.0684 per traversed cm	2.96 cm^2 cross section with X/X0 of 0.022 per traversed cm	4.321 cm x 1cm x 1 cm with 0.102 X/X0 per traversed cm

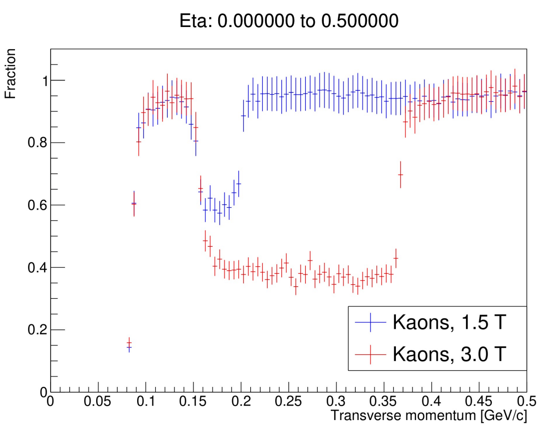
Update on L. Greiner, https://indico.bnl.gov/event/8231/contributions/37955/
2nd EIC Yellow Report Workshop at Pavia University (2020)

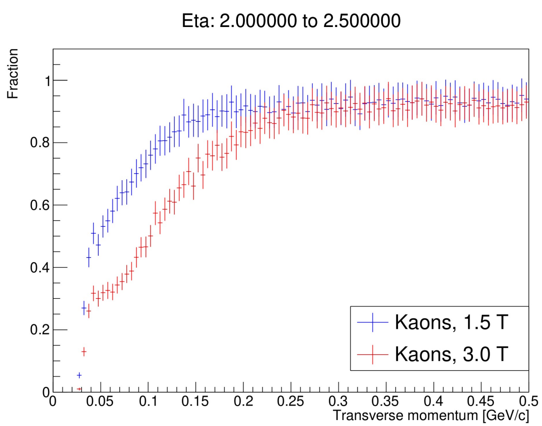
EIC YR – Hybrid Tracking and Vertexing Concept

- Minimum p_T threshold
  - Low transverse momentum range, 0-0.5 GeV/c
  - Two different magnetic fields: 1.5 T and 3.0 T
  - Study made for pions and kaons separately
  - Investigating which fraction of events is reconstructable, using a basic Kalman filter algorithm
  - Note: algorithms will improve, but this gives a measurement of the least we can do
  - Cutoff taken as the point where 90% of events can be reconstructed
  - This concept fully symmetric around interaction point

EIC YR – Hybrid Tracking and Vertexing Concept

- Minimum p_T threshold
  - The study spans the full pseudorapidity range of -4 to 4
    - Two examples are shown, for kaons
    - Reduction in efficiency in the middle comes from events spiralling in the TPC – can be improved with better reconstruction algorithms
  - The summary table shows an average value for pions and kaons
    - Outside of η = 3.25, reconstruction efficiency < 90%
  - Note: the cutoff in the table is taken as 90%. At lower momenta reconstruction is possible but less efficient

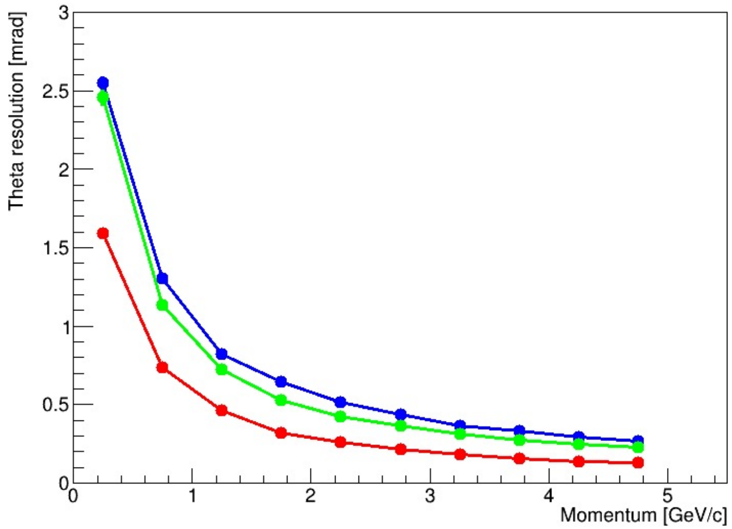


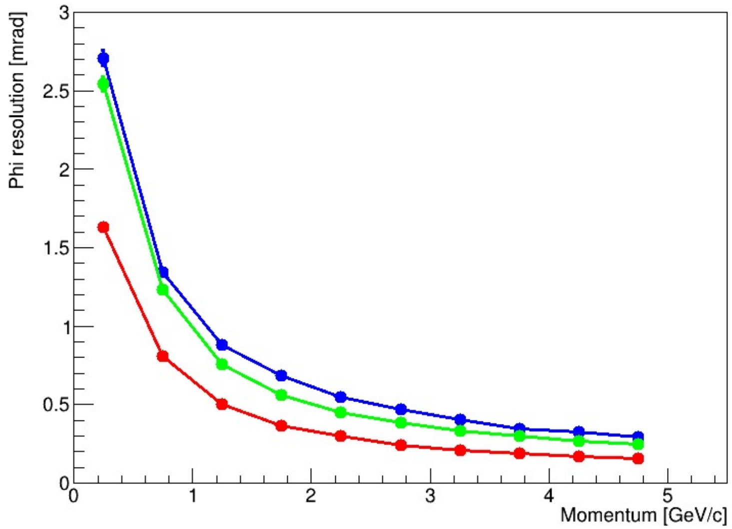


η interval	Min-p_T, 1.5 T	Min-p_T, 3.0 T
$-3.0 \leq \eta \leq -2.5$	100 MeV/c	150 MeV/c
$-2.5 \leq \eta \leq -2.0$	130 MeV/c	220 MeV/c
$-2.0 \leq \eta \leq -1.5$	70 MeV/c	160 MeV/c
$-1.5 \leq \eta \leq -1.0$	150 MeV/c	300 MeV/c
$-1.0 \leq \eta \leq 1.0$	200 MeV/c	400 MeV/c
$1.0 \leq \eta \leq 1.5$	150 MeV/c	300 MeV/c
$1.5 \leq \eta \leq 2.0$	70 MeV/c	160 MeV/c
$2.0 \leq \eta \leq 2.5$	130 MeV/c	220 MeV/c
$2.5 \leq \eta \leq 3.0$	100 MeV/c	150 MeV/c

EIC YR – Hybrid Tracking and Vertexing Concept

- Angular resolutions at vertex

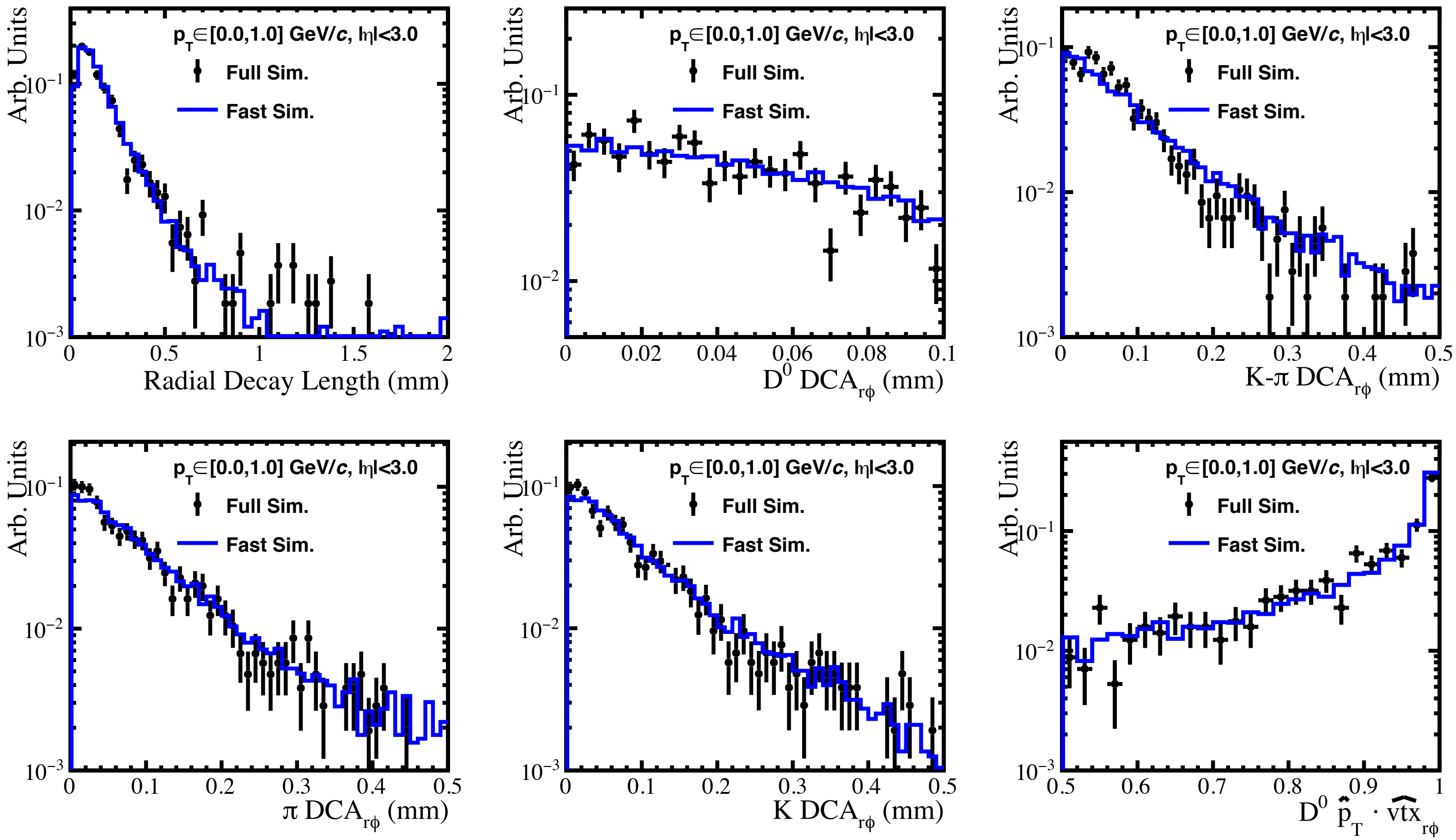




	Green	Blue	Red (ITS3-derived EIC SVT)
Beam pipe radius [mm]	18	**31**	**31**
x/X0 vertex	0.3%	0.3%	**0.05%**
x/X0 tracking layers	0.8%	0.8%	0.8%
Pixel pitch [um]	20	20	**10**

EIC YR – All-Silicon Tracking and Vertexing Concept

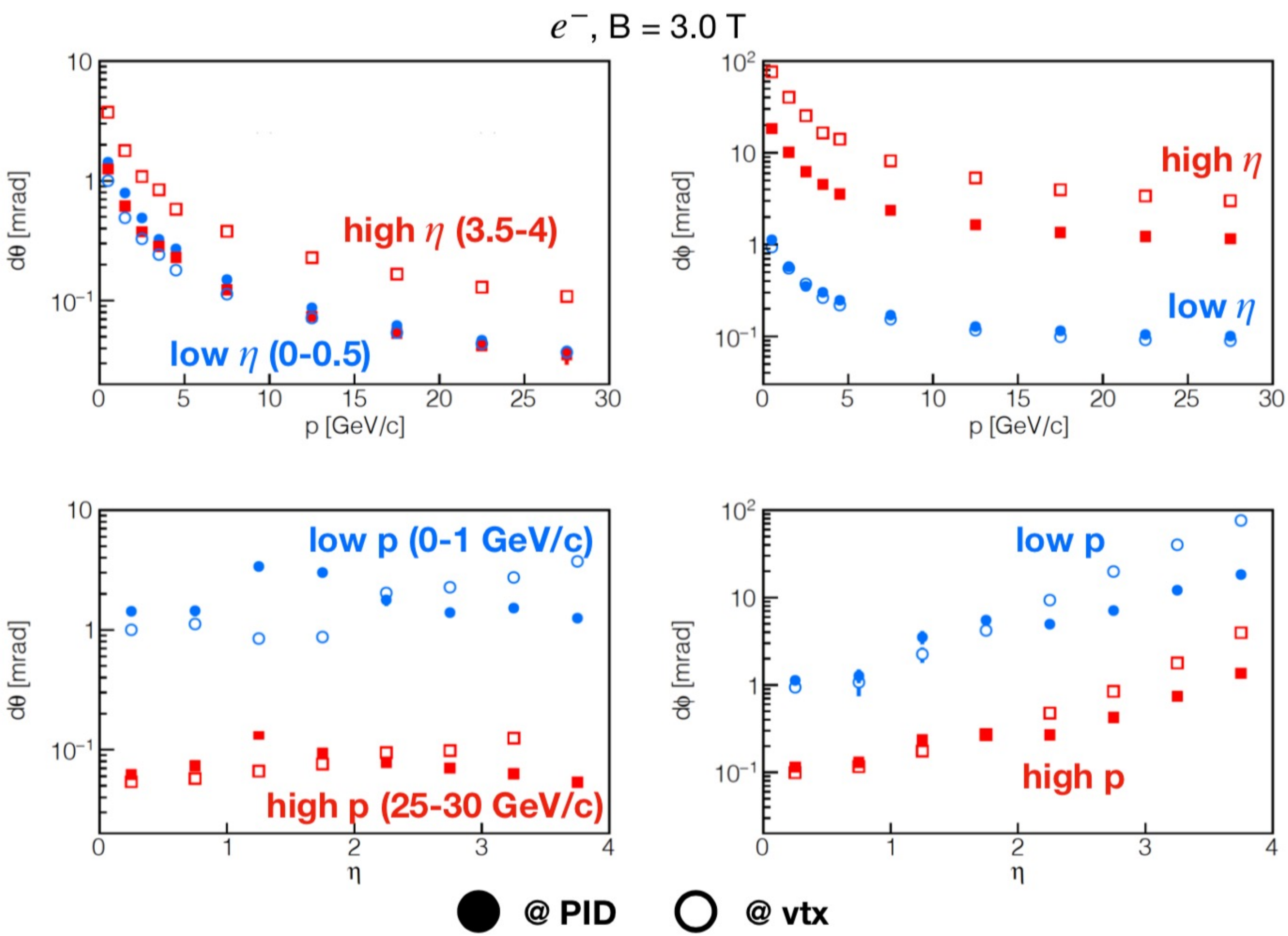
- GEANT-based simulations were used to extend the “fast” simulation framework (used for most physics studies in the YR), with decay topological variables



See also arXiv:2102.08337

EIC YR – All-Silicon Tracking and Vertexing Concept

Angular resolutions, for a 20 μm pixel pitch, at the vertex and PID detectors



EIC YR – All-Silicon Tracking and Vertexing Concept

Effect of 25 mrad crossing angle of the hadron beam on dp/p for 20 μm pixel pitch